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DIFFERENTIAL FEEDING ON BARLEY VARIETIES BY GRASSHOPPERS

D. S. McBean

Department of Plant Science
University of Alberta

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DIFFERENTIAL FEEDING ON BARLEY VARIETIES
BY GRASSHOPPERS

D. S. McBean
Department of Plant Science

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D. S. McBean

INTRODUCTION

Grasshoppers are a major pest nearly every year in parts of southern Saskatchewan and Alberta. Official figures as reported in the Annual Reports of the Field Crops Commissioner show that in Saskatchewan for the ten-year period 1936 - 1945, crops to the value of $81,310,000 were destroyed by grasshoppers. This represents an average annual loss of 4.6 percent of the wheat and 6.3 percent of all other crops grown in the province during that period. This figure minimizes the importance of the problem in that most of the grasshopper damage occurs in the southern part of the province. Consequently the average annual loss in such areas is considerably higher. For example, when the annual loss for the province in 1939 was 6.2 percent of the wheat and 12.6 percent of all other crops, there was

18.0 percent and 40.4 percent damage respectively in Crop District 2. No comparable statistics are available for the province of Alberta where the general situation with regard to grasshoppers is similar.

During the course of testing varieties of cereal crops at the Dominion Experimental Station, Swift Current, Saskatchewan, a natural infestation of grasshoppers caused considerable damage in some tests. Wide varietal differences in the amount of grasshopper damage were noted, especially among barley varieties. A survey of the literature concerning insect-resistant plants failed to reveal any published work on such damage, and it was evident that there was considerable difference of opinion among agronomists and entomologists who had observed differential feeding of grasshoppers. Consequently, in 1944, it was decided to investigate further the reaction of barley varieties to grasshopper damage. Tests were conducted from 1944 - 1947 inclusive. The objective of such tests has been to determine whether there are consistent differences in the amount of damage suffered by barley varieties exposed to grasshopper attack; and if so, to determine which, if any, agronomic characters may be associated with "resistance".

This thesis presents the results of the above-mentioned tests and discusses their probable significance.

REVIEW OF LITERATURE

Excellent reviews of the resistance of plants to insect damage have been published recently (21, 25). It is proposed to mention here only that literature dealing specifically with grasshoppers, and to mention other crop-insect relationships in the discussion of the results of the present study.

It is a common belief that grasshoppers are a manace to any and all crops, although the literature contains scattered references to the contrary. Ball (2) noted that of 250 species of Orthoptera in Arizona the majority are either beneficial or harmless, and extremely specific in their food habits. Several investigators (19, 23, 28) and more recently Brunson and Painter (7) have recorded wide differences in the amount of grasshopper damage suffered by corn and sorghum. Brunson and Painter noted several instances in which corn in one field was eaten to the ground while sorghum in an adjacent field was practicaly uninjured. No explanation of this preference for corn was offered by the authors, but it may be a specific characteristic of certain American Acrididae, since Uvarov (28) records an Asiatic species that feeds chiefly on sorghums.

Isley (16) studied the interrelationship of 150 species of grasses, forbs, garden and crop plants with 40 species of Acrididae in Texas. He concluded that vigorous individuals will starve in the presence of abundance if the particular host species are not present.

Criddle (9) found that while there are some plants, for example *Agropyron Smithii*, which are palatable to a great many grasshoppers, there are others, such as *Setaria viridis*, which these insects rarely touch.

Mail (19) reported an instance of half-grown mymphs of *M. bivittatus* (Say) and *M. differentialis* (Thos.) which, when released in a greenhouse, attacked only grapefruit and palm plants which they damaged severely out of a choice of twenty-six kinds of plants. The palm plants were hard and stringy!

Andrewartha (1), studying the significance of grasshoppers in relation to soil conservation in Australia, recommended the use of *Atriplex vesicarium* as it is inedible for grasshoppers.

Differences in the amount of damage suffered by various cereal crops have been noted on several occasions. Jones (18) in 1937, observed two varieties of durum wheat, grown in randomly replicated plots, to be completely

stripped by a heavy infestation of grasshoppers, whereas, 100 plots of spring and winter wheat in the same test were uninjured. Smith (25) noted that, during the severe grasshopper infestation of 1938 in North Dakota, the most damage, in descending order, was in barley, oats, wheat, corn and sorghum. Riley (23) in discussing the feeding habits of the Rocky Mountain locust, listed corn, wheat, rye and oats in the order of preference.

That such specificity in the feeding habits of grasshoppers should extend to varieties of crops is not surprising. In South America several investigators (5, 14, 20) have studied the resistance of corn varieties to grasshopper attack. While the cause for the resistance of "Amargo" maize has not been definitely established, it has been shown by Marchioni (20) that it is possible to select hybrid lines from a cross between "Amargo" and a susceptible variety that are as resistant as the resistant parent.

Brunson and Painter (7) obtained outstanding instances of differential damage among corn varieties, top crosses and hybrids grown in Kansas. It is the opinion of these investigators that neither the gregarious instincts of the grasshoppers, nor differences in maturity of the tested strains, was of importance in determining the dif-

ferential injury noted. As a rule, the varieties and inbred lines showing the most resistance originated in areas where grasshoppers are a natural element of the environment. It was suggested, therefore, that natural selection operating in the development of adapted varieties has tended to intensify resistance to grasshoppers in such varieties.

Hume (15) found that varieties of dent corn suffered more grasshopper damage than did varieties of flint corn.

Hermann and Eslick (12) reported wide differences in the amount of damage sustained by 405 selections from 28 species of grasses exposed to the attack of four economic species of grasshoppers. These differences were equally evident between selections within a species and between species. They concluded that if the inheritance of a selection influences its susceptibility to attacks by grasshoppers, it may be possible to select strains of grasses which will be more highly resistant than any now produced.

Clark (8, page 223) reported Ceres wheat to be less damaged by grasshoppers than other varieties grown in North Dakota.

Smith (25) noted wide differences in the amount of damage caused by Lesser Migratory grasshoppers feeding on varieties of spring wheat. Stage of maturity and

amount of rust at the time of grasshopper feeding appeared to influence the degree of damage, although exceptions to both factors were recorded.

Jacobson and Farstad (17) in a study of 41 varieties of spring wheat found distinct varietal differences in the number of heads cut off by grasshoppers.

MATERIALS AND METHODS

Barley varieties were grown in replicated tests at several locations during each of the four years, 1944 - 1947. The damage suffered by these tests resulted from naturally occurring populations of grasshoppers. Such populations were composed of varying percentages of several species, chiefly Melanoplus mexicanus mexicanus (Saus.), Melanoplus bivittatus (Say) and Camnula pellucida (Scudd.). No attempt was made to determine accurately the percentage of each species present at each location. In 1947, the author was indebted to Mr. R. M. White* for an accurate determination of the species of grasshoppers present at Burdett, Alberta. All other percentages reported are approximations only.

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* R. M. White. Entomologist, Dominion Entomoological Laboratory, Lethbridge, Alberta

In 1944, thirty-seven varieties of barley were grown at four locations in single, 5-foot row plots, replicated six times. In 1945, forty-one varieties were grown at two locations in single rod row plots replicated six times. In 1946, forty-two varieties were grown at two locations in 7 x 6 rectangular lattices. In 1947, forty-two varieties plus ninety-eight hybrid lines from a Prospect x Hannchen population, were grown at five locations, with the 10-foot, single row plots arranged as a triple lattice repeated. The Prospect x Hannchen hybrids were pure breeding lines selected to secure a range in maturity from one parent to the other, together with as many combinations of the parental agronomic characters as possible. These hybrids were included in the 1947 tests with the view to examining the relationship between agronomic characters and grasshopper damage. The parents were chosen because they represent extremes in susceptibility to grasshopper damage and also differ widely in agronomic characters.

The damage to barley reported in this thesis refers to the percentage of heads dropped, unless otherwise stated. Estimates of damage were made by a single recorder, except for tests grown in 1945 when the average of two independent estimates was recorded. Different individuals estimated damage in 1944, 1945 and 1946. In 1944 estimates of damage at two locations were made at

weekly intervals from the beginning of the infestation until harvest. Estimates of damage in subsequent tests were taken at the time the crop would normally be harvested.

Agronomic notes were taken on the varieties and hybrids grown at Swift Current under grasshopper-free conditions. The days required for a variety to head has been used instead of 'days to mature', since such a note is a more accurate measure of maturity under Swift Current conditions. Other notes on morphological characters such as shattering, neck strength, strength of straw, etc., are explained in footnotes to the tables concerned.

The analyses of variance in lattice designs and the determination of significant differences follow closely the methods outlined by Goulden (10). The analyses of percent damage were made after adding one to all percentages and converting to $\sin^2\theta$, as recommended by Bliss (4). Correlation coefficients were determined using the formula suggested by Hayes and Immer (11, page 329). Tests of the homogeneity of several estimates of variance, with a view to combining data collected from several stations and years, were calculated according to the method proposed by Bartlett (3).

RESULTS

Varietal susceptibility and its relationship to maturity

1944

Grasshoppers were present in large numbers at Piapot, Sask., when the crop emerged. Emergence of the plants was slow and irregular due to drought. The plants that did emerge were kept eaten to the ground until further growth ceased. No varietal differences were apparent.

At Swift Current and Saskatchewan Landing in Sask., and at Carmangay, Alta., no appreciable damage from grasshoppers occurred until the crop was well headed. The average damage in percent for each variety at each station and the days to head as recorded at Swift Current are presented in Table I. Highly significant differences in the amount of damage sustained by varieties were obtained at each of the three stations (Table IX). Highly significant positive correlations between the percent damage as recorded at each station were obtained (Table II). There was a highly significant positive correlation between the percent damage and days to head at each station (Table II).

An analysis of estimates of damage taken at various dates at both Swift Current and Saskatchewan Landing showed no significant interaction between varieties and dates at either station. Only final estimates of damage, therefore, were recorded in subsequent years.

The five-foot row plot did not provide sufficient material upon which to base accurate estimates of damage. Plots in subsequent tests were either rod rows or ten-foot rows.

TABLE I

Percent Grasshopper Damage and Days to Head - 1944.

	Percent heads dropped				
Variety	Sw.C. (1)	Sask. Land.(2)	Carmangay (3)	Average	Days to head (4)
Gordon	93	73	100	89	64
Glabron	80	82	100	87	63
Wisc. Ped. 38	90	72	99	87	64
Duckbill	87	72	100	86	70
O.A.C. 21	85	68	100	84	61
Michigan	90	62	100	84	67
Newal	86	57	100	81	63
Canadian Thorpe	87	55	100	81	70
Odessa	80	67	94	80	67
Alpha	92	50	99	80	64
Byng	83	56	100	80	63
Nobarb	80	58	100	79	64
Horn	73	61	100	78	63
California Mariout	77	54	99	77	57
Rex	75	63	92	77	63
Prospect 3256	73	58	98	76	57
Regal	78	68	82	76	63
H. medicum	70	55	98	74	61
Titan	58	66	96	73	59
Trebi	63	44	98	68	60
Colsess	35	74	95	68	58
Smyrna	67	38	98	68	58
Sans Barb x Trebi	57	45	99	67	60
Pros. x Stav.3825	90	42	69	67	58
Plush	42	61	96	66	61
Black Barbless	58	44	91	64	61
Rika	62	57	71	63	57
Type Pusa 21	50	33	98	60	52
H. zecofense	27	48	90	55	66
Pros. x Stav.3823	45	28	86	53	58

TABLE I (continued)

Variety	Percent heads dropped Sw.C. (1)	Sask. Land.(2)	Carmangay (3)	Average	Days to head (4)
Cape	30	48	66	48	66
Type 4 Punjab	40	26	78	48	52
Gatami	52	42	49	48	58
Glacier	30	36	70	45	56
H.persicum	22	41	68	44	61
H.pallidum	20	20	32	24	49
Lansdale	18	21	22	20	53

(1) Swift Current, average of 3 replicates.
(2) Saskatchewan Landing, average of 6 replicates.
(3) Carmangay, Alta., average of 4 replicates.
(4) Notes taken at Swift Current. Average of 5 replicates to nearest whole day.

TABLE II

Correlation Coefficients Obtained Between Damage and Maturity; and Between Damage Recorded at Three Locations in 1944.

Correlation between	Swift Current	Saskatchewan Landing	Carmangay
Days to head(1) and % heads dropped at	0.549	0.657	0.537
% heads dropped at Swift Current and	-	0.628	0.649
% " " " Sask. Landing and	-	-	0.634

(1) Notes taken at Swift Current under grasshopper-free conditions.
5% level 0.32 5; 1% level 0.418.

1945

Fairly heavy infestations of grasshoppers occurred at both Cabri, Sask., and Nobleford, Alta. At Nobleford the grasshoppers commenced feeding as the crop neared maturity. At Cabri a somewhat different situation obtained. Feeding began early in June before any varieties had headed. This feeding

was concentrated on certain varieties while others were practically uninjured. The more susceptible varieties were kept eaten to the ground throughout the season. Eventually most of the foliage was removed from all varieties. By the time the crop was mature, the more susceptible varieties had been completely destroyed, but the more resistant ones had lost only their leaves and less than ten percent of their heads (see Fig. 1 and 2). Gradations between these extremes were also found.

A summary of the varietal damage together with the days to head as recorded at Swift Current is shown in Table III. Very highly significant differences in the amount of varietal damage occurred in these tests (Table IX). There were highly significant positive correlations between the amount of damage at the stations, and between the amount of damage at each station and the days to head (Table IV).

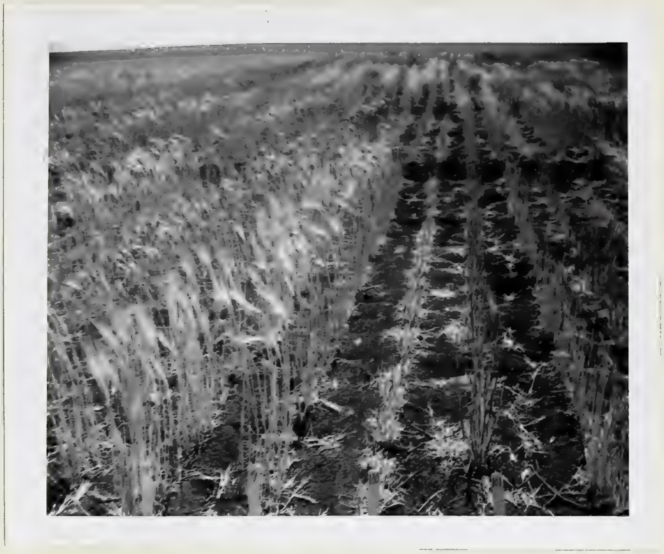

Fig. 1 Cabri, 1945.

Plot 98 - Pros. x Stav. 3823 - 15% damage.
Plot 99 - Prospect.......... - 20% "
Plot100 - Canadian Thorpe... -100% "
Plot101 - Rex............... -100% "

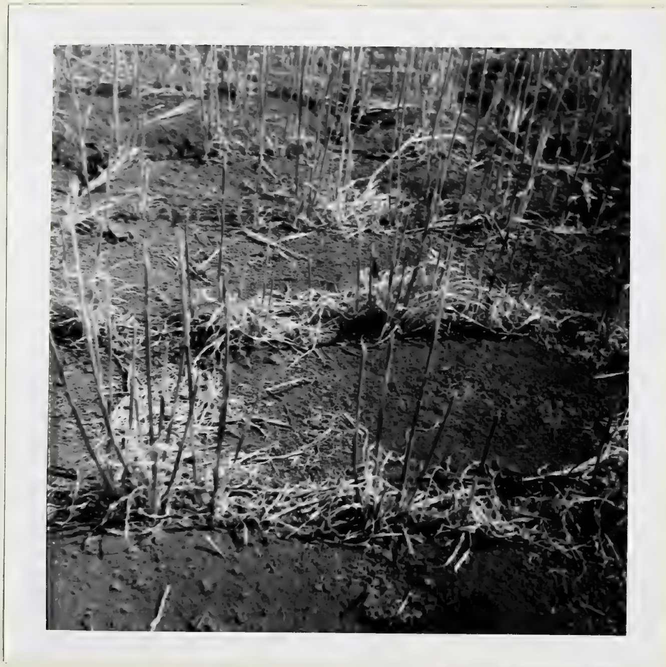

Fig. 2 Cabri, 1945. Note heads dropped and straw eaten.

TABLE III

Percent Grasshopper Damage and Days to Head - 1945

	Percent heads dropped (1)			Days to head (2)
	Cabri	Nobleford	Average	
Canadian Thorpe	100	82	91	78
Gordon	100	72	86	77
Regal	94	77	86	71
O.A.C. 21	94	74	84	71
Sanalta	100	63	82	74
Norbarb	97	65	81	70
Wisconsin Ped. 38	93	67	80	74
Montcalm	94	60	77	74
Glabron	93	58	76	70
Binder	99	51	75	75
Rex	98	51	74	71
Horn	98	47	72	72
Newal	79	63	71	68
Michigan	94	41	68	72
Mars	84	48	66	66
Byng	88	42	65	70
Plush	84	24	54	71
H. medicum	67	14	40	68
Sans Barb x Trebi	64	2	33	66
Velvon	46	8	27	67
Calif. Mariout	28	26	27	61
H. zecofense	16	32	24	66
Trebi	35	2	18	68
Black Barbless	33	3	18	66
Titan	26	3	14	66
Gatami	23	1	12	62
Prospect 3270	20	3	12	62
Smyrna	21	1	11	67
Prospect 3256	19	2	10	63
Pros. x Stav. 3823	16	1	8	64
Colsess	12	5	8	66
Pros. x Stav. 3825	15	1	8	67
Warrior	15	1	8	63
H. persicum	14	1	8	66
Lico	12	2	7	65

TABLE III (continued)

Variety	Percent heads dropped(1) Cabri	Nobleford	Average	Days to head (2)
Glacier	8	2	5	60
Rika	32	-	-	61
Type Pusa 21	24	-	-	58
Type 4 Punjab	18	-	-	56
H. pallidum	1	-	-	54
Lansdale	1	-	-	56

(1) Average of 6 replicates to nearest whole number.
(2) Swift Current only - average of 6 replicates to nearest whole number.

TABLE IV

Correlation Coefficients Obtained Between Damage and Maturity; and Between Damage Recorded at Two Locations in 1945.

Correlation between	Cabri	Nobleford
Days to head(1) and % heads dropped at	0.838	0.791
% heads dropped at Cabri and	-	0.881

(1)As recorded at Swift Current.
5% level 0.300. 1% level 0.388.

1946

Only light infestations of grasshoppers occurred at Cabri and Shaunavon, Sask., in 1946. Damage to varieties grown at Cabri was not sufficient to warrant making varietal comparisons. At Shaunavon damage was slightly more severe and notes on the amount of leaf damage and head dropping were made when the crop was mature.

The percentage of leaf and head damage due to grasshoppers is shown in Table V for varieties grown at Shaunavon, together

with the days to head as recorded at Swift Current. No analysis of the data has been attempted. As in 1944 and 1945, it was apparent that the later maturing varieties were most damaged.

TABLE V

Percent Grasshopper Damage at Shaunavon and Days to Head - 1946

Variety	Leaf damage %	Heads dropped %	Days to head (1)
Canadian Thorpe	97	41	78
Norbarb	73	28	76
Sanalta	98	22	78
Gordon	80	22	77
Hannchen	71	17	74
Montcalm	69	9	71
O.A.C. 21	29	9	72
Wisconsin Ped. 38	23	8	70
Glabron	64	6	70
Rex	53	6	71
Horn	48	4	71
Newal	22	2	71
Michigan	21	2	72
Regal	22	1	70
Velvon	26	0	68
Rika	19	0	65
Mars	18	0	68
Plush	12	0	68
Byng	10	0	72
Type 4 Punjab	10	0	58
H. zecofense	9	0	68
S. B. x Trebi	8	0	68
Pros. x Stav. 3825	8	0	67
Type Pusa 21	8	0	59
Glacier	3	0	68
Titan	2	0	68
Pros. x Stav. 3823	2	0	62
Black Barbless	2	0	64
Colsess	2	0	66
Prospect 3256	2	0	64

TABLE V (continued)

Variety	Leaf damage %	Heads dropped %	Days to head(1)
Trebi	1	0	66
Calif. Mariout	1	0	58
H. persicum	1	0	66
Warrior	1	0	63
Compana	0	0	66
H. medicum	0	0	70
Gatami	0	0	70
Prospect 3270	0	0	66
Smyrna	0	0	67
Lico	0	0	67
H. Pallidum	0	0	58
Lansdale	0	0	58

(1) Notes taken at Swift Current, Sask., average of 3 replicates.

1947

No grasshopper infestation occurred at Shackelton, Sask., and consequently that test was abandoned. Fairly heavy infestations occurred at Gravelbourg, Shaunavon and Herschel in Saskatchewan, and at Burdett in Alberta. No exact counts to determine the density and composition of the grasshopper populations were made. However, it is believed that the figures shown in Table VI are sufficiently accurate for the purpose of comparisons between tests.

TABLE VI

Density and Composition of Grasshopper Populations Infesting Barley Tests Grown during 1947.

Station	Species present	Proportion of each specie in total pop.	Density all species per square yard
Gravelbourg and Shaunavon	*M. bivittatus* (Say)	5	8
	C. pellucida (Scudd.)	4	
	M. m. mexicanus (Scuss.)	2	
Herschel	*C. pellucida* (Scudd.)	10	15
	M. m. mexicanus (Scuss.)	1	
	M. bivittatus (Say)	1	
Burdett	*M. m. mexicanus* (Sauss.)	20	15
	M. bivittatus (Say)	1	
	M. packardi (Scudd.)	1	

Occasional individuals of several other species were present at all locations but these were of no economic importance.

General feeding by grasshoppers was not apparent in any test until about the time the earliest varieties were beginning to head. Wide differences in the amount of damage suffered by adjacent plots were readily noticeable (see Figs. 3, 4, 5 and 6). The mean damage to each variety and hybrid grown at the various sites is shown in Table VII, together with the days to head as recorded at Swift Current. Highly significant varietal differences were obtained in each of the four tests (Table IX).

There were highly significant positive correlations between the percent damage to varieties at Gravelbourg, Shaunavon and Burdett, and the days to head as recorded at Swift Current.

A highly significant negative correlation between the damage to varieties and hybrids grown at Herschel and the days to head as recorded at Swift Current was obtained (Table VIII). When the damage to varieties and hybrids at Herschel were each correlated independently with the days to head, the resulting correlation coefficients were obtained; for varieties -0.171 (significant) and for hybrids - 0.274 (highly significant).

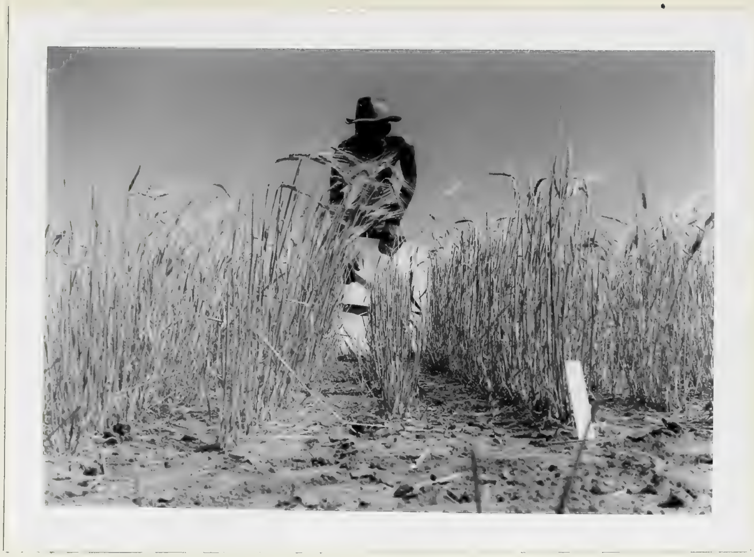

Fig. 3 Gravelbourg, 1947. Prospect............ 20% damage.
Hannchen............100% "
P. x H. 4630........ 25% "

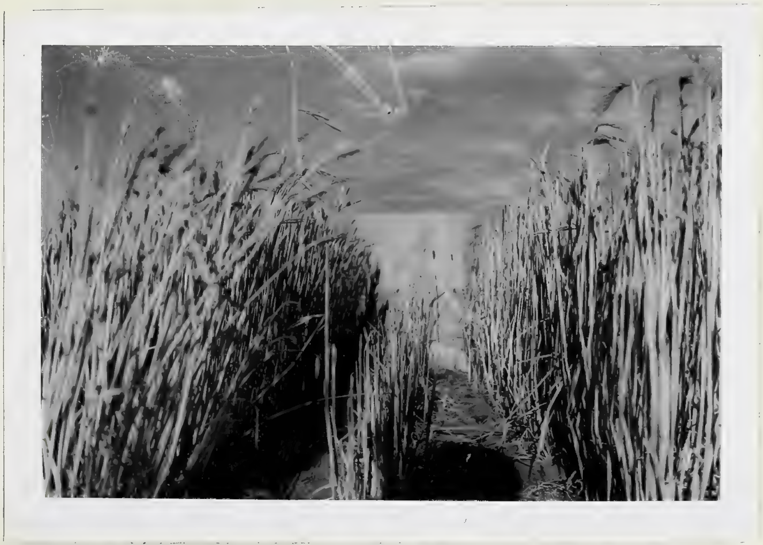

Fig. 4 Burdett, 1947. P. x H. 4614........... 5% damage.
Hannchen...............100% "
P. x H. 4653........... 50% "

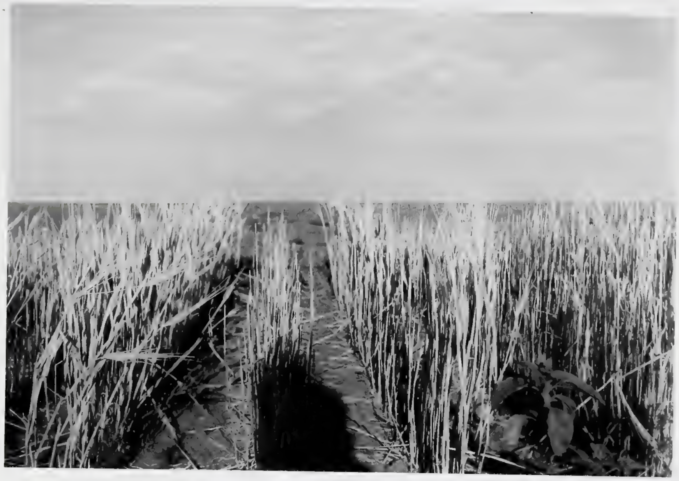

Fig. 5 Burdett, 1947. Lansdale.............. 5% damage.
P. x H. 4606...........100% "
H. pallidum........... 5% "

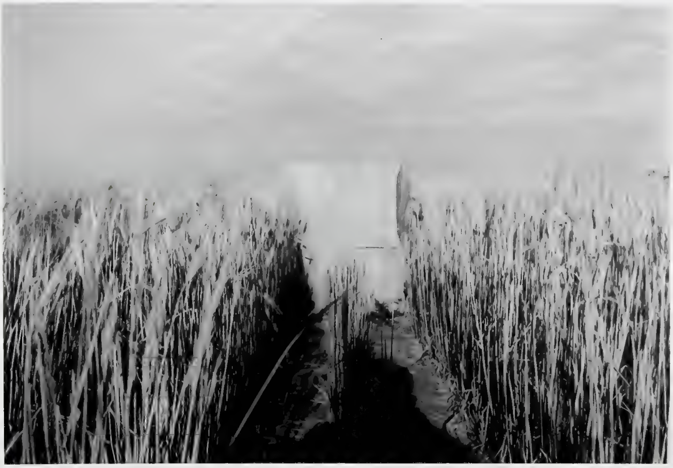

Fig. 6 Burdett, 1947. Glacier............... 25% damage.
Hannchen.............. 100% "
P. x H. 4642.......... 98% "

TABLE VII

Percent Grasshopper Damage and Days to Head - 1947.

Variety or hybrid	Percent heads dropped (1)					Days to
	G'bourg	Shaun.	H'schel	Burdett	Av.	head(2)
Hannchen	83	85	91	100	90	59
P. x H. 4690(3)	62	92	81	100	84	64
x 4678	75	72	87	100	84	55
Can. Thorpe	56	91	81	100	82	62
Gordon	42	60	97	100	75	61
O.A.C. 21	35	58	99	100	73	54
Glabron	42	50	98	98	72	55
P. x H. 4666	29	60	96	100	71	56
x 4616	49	42	95	99	71	53
x 4625	48	38	97	100	71	54
x 4676	38	66	76	100	70	59
Sanalta	58	66	56	100	70	59
Nobarb	36	56	89	99	70	57
Horn	43	43	94	99	70	57
P. x H. 4619	28	52	99	100	70	57
x 4640	39	39	97	99	68	54
x 4691	43	78	52	100	68	64
Wis. Ped. #38	40	44	88	100	68	57
P. x H. 4636	20	58	92	100	68	61
x 4655	41	58	68	100	67	61
x 4605	28	67	69	100	66	58
Regal	34	31	99	100	66	56
Rex	32	51	80	100	66	57
P. x H. 4672	40	41	81	100	66	59
Mars	37	31	99	95	66	52
P. x H. 4606	29	38	93	100	65	57
x 4677	42	65	52	100	65	60
x 4644	38	23	97	100	64	54
x 4641	26	44	88	100	64	54
Newal	29	29	98	100	64	54
P. x H. 4627	23	41	92	100	64	55
x 4613	28	52	75	100	64	59
Byng	16	46	96	93	63	54
P. x H. 4602	22	55	62	100	62	55
x 4651	35	23	90	100	62	56

TABLE VII (continued)

	Percent heads dropped (1)					Days to
Variety or hybrid	G'bourg	Shaun.	H'schel	Burdett	Av.	head(2)
P. x H. 4652	28	27	92	100	62	56
x 4689	34	14	98	100	62	52
x 4601	23	44	79	100	62	56
x 4660	38	21	90	96	61	50
x 4633	28	21	96	100	61	58
x 4697	31	34	79	100	61	57
x 4694	42	40	62	100	61	54
x 4658	19	46	80	99	61	58
x 4649	23	35	85	100	61	54
x 4669	21	24	96	100	60	53
Montcalm	22	32	87	100	60	54
P. x H. 4618	24	30	86	100	60	60
x 4607	28	30	85	96	60	58
x 4671	20	41	77	100	60	55
x 4629	30	25	83	100	60	55
x 4626	27	23	86	100	59	56
x 4648	29	19	87	100	59	54
x 4684	26	14	98	96	58	52
x 4687	28	6	99	100	58	55
x 4674	14	29	90	100	58	61
x 4628	26	49	58	100	58	57
x 4637	25	14	94	98	58	53
x 4611	27	36	68	100	58	55
x 4673	18	14	98	100	58	56
x 4661	28	18	85	98	57	55
x 4679	21	13	97	96	57	52
x 4632	23	38	66	100	57	54
x 4623	25	16	86	100	57	57
x 4621	29	6	91	100	56	50
x 4603	22	11	92	100	56	55
x 4696	28	21	74	100	56	56
x 4642	19	27	78	99	56	55
x 4668	20	39	68	94	55	54
Michigan	28	20	73	100	55	60
P. x H. 4682	22	11	94	92	55	50
x 46152	14	13	94	97	54	49
x 4683	19	26	74	99	54	53
x 4681	18	12	91	95	54	51
H. medicum	8	12	95	100	54	54
P. x H. 4670	15	4	94	99	53	53

TABLE VII (continued)

Variety or hybrid	Percent heads dropped (1)					Days to head(2)
	G'bourg	Shaun.	H'schel	Burdett	Av.	
P. x H. 4635	30	54	28	100	53	57
x 4617	19	6	95	92	53	52
x 4647	13	21	78	99	53	51
x 4665	18	9	83	99	52	53
x 4620	15	6	92	96	52	49
Plush	10	10	89	100	52	54
Smyrna	12	4	98	95	52	58
P. x H. 4638	11	18	80	99	52	54
x 4604	18	5	98	87	52	52
Sans Barb x Trebi	16	14	78	100	52	53
P. x H. 4686	12	15	80	100	52	55
x 4663	12	11	86	98	52	51
Trebi	11	9	86	100	52	54
Gatami	5	2	98	100	51	51
P. x H. 4646	17	10	90	87	51	54
Titan	8	4	96	96	51	51
Type Pusa 21	7	2	98	96	51	46
P. x H. 4698	18	9	75	100	50	52
x 4639	11	4	93	91	50	52
x 46151	22	13	62	100	49	56
x 4643	8	11	77	99	49	54
x 4692	9	8	98	80	49	53
x 4680	10	4	99	82	49	54
x 4645	13	6	77	100	49	53
x 4650	8	2	98	87	49	52
x 4622	8	6	96	85	49	52
Rika	10	3	84	98	49	50
P. x H. 4654	10	4	97	83	48	54
x 4675	8	6	96	82	48	51
H. zecofense	4	10	79	99	48	54
H. persicum	4	2	98	88	48	55
P. x H. 4685	12	18	72	89	48	55
x 4630	15	18	74	84	48	57
Pros. x Stav. 3825	6	4	81	100	48	53
Pros. x Stav. 3823	8	4	92	87	48	51
Type 4 Punjab	5	4	98	84	48	46
Calif. Mariout	5	2	97	87	48	48
P. x H. 4659	15	7	69	97	47	53
x 4634	16	5	85	82	47	52
x 4615	27	6	65	90	47	55

TABLE VII (continued)

	Percent heads dropped (1)					Days to
Variety or hybrid	G'bourg	Shaun.	H'Schel	Burdett	Av.	head(2)
Black Barbless	4	2	82	99	47	53
Prospect 3270	13	4	83	87	47	52
P. x H. 4693	12	5	78	92	47	49
x 4653	14	10	77	86	47	56
x 4612	16	5	91	73	46	50
x 4610	11	6	78	89	46	55
x 4609	25	11	51	96	46	50
x 4624	20	8	68	86	46	54
Velvon	10	9	61	100	45	54
P. x H. 4688	7	2	94	77	45	51
x 4657	32	10	46	90	44	53
x 4667	20	12	46	97	44	56
x 4608	13	3	90	68	44	51
Colsess	2	2	87	82	43	53
P. x H. 4662	14	7	53	95	42	52
Prospect 3256	13	5	65	81	41	52
Glacier	10	1	88	63	40	51
P. x H. 4664	6	3	83	70	40	50
P. x H. 4614	11	3	72	75	40	54
Compana	4	2	88	64	40	55
P. x H. 4656	10	3	92	52	39	52
Lico	5	2	66	81	38	52
Warrior	2	2	65	82	38	49
H. pallidum	4	2	99	36	35	45
Lansdale	4	2	90	20	29	46

(1) Each station figure the average of six replicates.
(2) Notes taken at Swift Current, average of 3 replicates.
(3) Prospect X Hannchen hybrid.

TABLE VIII

Correlation Coefficients Obtained Between Damage and Maturity, and Between Damage Recorded at Four Locations in 1947

Correlation between	G'bourg.	Shaun.	H'chel.	Burd.
Days to head(1) and % heads dropped at	0.566**	0.711**	-0.253**	0.483**
Days to head(1) and % heads dropped at (varieties)	0.692**	0.704**	-0.171*	0.566**
Days to head(1) and % heads dropped at (hybrids)	0.451**	0.621**	-2.74 **	0.394**
% heads dropped at G'bourg. and	-	0.805**	-0.098	0.442**
% heads dropped at Shaun. and	-	-	-0.188*	0.438**
% heads dropped at H'chel. and	-	-	-	-0.130

(1) As recorded at Swift Current.

* Significant at 5% level.

** Significant at 1% level.

TABLE IX

Variety Mean Squares and Standard Errors of the Means in Percent Obtained from the Analyses of Grasshopper Tests, 1944 - 1947

Year		Mean square (1)	S.e.m. %
1944	Swift Current	767.03	11.5
	Saskatchewan Landing	657.50	9.9
	Carmangay	1058.18	7.3
1945	Cabri	4582.76	6.8
	Nobleford	2761.64	13.6
1947	Gravelbourg	737.37	14.1
	Shaunavon	1608.42	14.5
	Herschel	858.41	7.4
	Burdett	651.60	6.6

(1) All mean squares are significant at the 1% level.

Varietal Susceptibility in Relation to Other Agronomic Characters

The percentage grasshopper damage to varieties grown at Cabri in 1945, together with various agronomic characters as determined at Swift Current under grasshopper-free conditions, are presented in Table 10. The average percentage of grasshopper damage to Prospect, Hannchen and 98 Prospect x Hannchen selections grown in 1947 is shown in Table 11, along with agronomic characters as determined at Swift Current under grasshopper-free conditions.

No analyses of these data has been attempted since it is believed that, in the unlikely event that correlations between damage and certain agronomic characters were established, they would be misleading.

TABLE X

Percent Damage at Cabri and Agronomic Characters as Determined at Swift Current, 1945

Variety	Percent damage$^{(1)}$	Height ins.	Angle head to stem$^{(2)}$	Shattering % (3)	Head drop-ping %$^{(4)}$	Leafiness (5)	Rows per head	Awn barbing$^{(6)}$
Can. Thorpe	100	19	22	0	3	9	2	R
Gordon	100	20	38	2	15	6	2	R
Sanalta	100	21	42	2	8	9	2	S
Binder	99	20	65	10	7	6	2	R
Rex	98	22	40	5	7	6	2	S
Horn	98	22	72	4	5	6	2	R
Nobarb	97	22	40	1	8	9	6	S
Michigan	94	20	65	3	13	3	2	R
O.A.C. 21	94	22	52	8	27	9	6	R
Regal	94	22	40	6	13	9	6	S
Montcalm	94	22	58	6	15	9	6	S
Wisc. Ped. 38	93	23	80	8	27	6	6	S
Glabron	93	25	40	3	15	9	6	S
Byng	89	19	42	10	17	9	6	S
Mars	84	22	30	8	8	4	6	S
Plush	84	22	70	5	5	9	6	S
Newal	79	24	58	9	7	6	6	S
H. medicum	67	22	50	1	5	4	2	S
Sans Barb x Trebi	64	21	20	1	0	4	6	S
Velvon	46	22	15	1	4	9	6	S

TABLE X (continued)

Variety	Percent damage (1)	Height ins.	Angle head to stem (2)	Shattering % (3)	Head dropping % (4)	Leafiness (5)	Rows per head	Awn barbing (6)
Trebi	35	19	25	0	2	6	6	R
Black Barbless	33	20	18	0	2	4	6	S
Rika	32	20	10	1	0	4	6	R
Calif. Mariout	28	20	50	2	12	4	6	R
Titan	26	21	12	0	3	6	6	S
Type pusa 21	24	14	10	0	0	2	6	R
Gatami	23	12	15	0	0	3	6	S
Smyrna	21	18	30	3	3	4	2	S
Prospect 3270	20	21	28	10	2	4	6	S
Prospect 3256	19	24	32	10	0	6	6	S
Type 4 punjab	18	14	10	0	0	2	6	R
H. zecofense	16	21	8	7	8	6	6	S
Pros. x Stav. 3823	16	21	22	1	2	4	6	S
Pros. x Stav. 3825	15	20	18	2	5	4	6	S
Warrior	15	20	0	5	1	6	6	hooded
H. persicum	14	20	18	0	0	6	2	S
Lico	12	21	15	0	0	4	6	S
Glacier	8	20	15	0	0	4	6	S
H. pallidum	1	14	30	0	0	1	6	R
Lansdale	1	15	38	0	7	1	6	R

(1) Percent heads dropped - average of six replicates at Cabri.
(2) Notes taken in degrees 0° = erect, 90° = right angles to stem.
(3) Taken two weeks after maturity.
(4) Natural head dropping recorded 2 weeks after maturity
(5) Rated 1 to 12 in order of leafiness. Very leafy = 12.
(6) Rough classification - two classes only.

TABLE XI

Percent Damage, 1947, and Agronomic Characters(1) of Ninety-eight Prospect x Hannchen Hybrids

Hybrid	Percent Damage(2)	Angle head to stem(3)	No. rows per head	Awn barbing	Height ins.
Hannchen	90	90	2	R	26
P. x H. 4690	84	5	6	R	30
x 4678	84	10	2	S	26
x 4666	71	90	6	R	27
x 4616	71	90	6	S	28
x 4625	71	90	6	S	28
x 4676	70	10	2	S	27
x 4619	70	75	6	S	27
x 4640	68	100	2	R	20
x 4691	68	20	2	R	23
x 4636	68	20	2	R	23
x 4655	67	30	2	R	26
x 4605	66	75	6	S	25
x 4672	66	90	6	S	28
x 4606	65	60	2	R	25
x 4677	65	5	6	R	29
x 4644	64	90	2	R	26
x 4641	64	80	6	R	26
x 4627	64	90	2	R	28
x 4613	64	75	6	S	28
x 4602	62	45	6	S	24
x 4651	62	80	2	R	26
x 4652	62	45	6	S	27
x 4689	62	75	6	R	27
x 4601	62	30	2	R	24
x 4660	61	90	6	R	26
x 4633	61	90	seg.	S	24
x 4697	61	90	seg.	seg.	26
x 4694	61	50	2	S	27
x 4658	61	90	6	seg.	26
x 4649	61	45	6	R	27

TABLE XI (continued)

Hybrid	Percent Damage(2)	Angle head to stem(3)	No. rows per head	Awn barbing	Height ins.
P. x H. 4669	60	60	2	R	28
x 4618	60	90	2	R	24
x 4607	60	15	6	S	27
x 4671	60	30	6	R	26
x 4629	60	90	2	S	24
x 4626	59	30	2	R	26
x 4648	59	90	6	S	26
x 4684	58	90	6	R	27
x 4687	58	45	seg.	seg.	30
x 4674	58	5	6	S	28
x 4628	58	5	2	R	27
x 4637	58	90	6	S	24
x 4611	58	90	2	R	27
x 4673	58	80	seg.	seg.	27
x 4661	57	15	2	S	27
x 4679	57	90	6	R	28
x 4632	57	90	2	S	27
x 4623	57	5	2	S	26
x 4621	56	60	6	R	28
x 4603	56	90	2	R	26
x 4696	56	75	2	S	28
x 4642	56	15	6	R	27
x 4668	55	10	6	S	26
x 4682	55	90	2	R	27
x 46152	54	45	6	R	26
x 4683	54	45	6	S	27
x 4681	54	90	2	R	27
x 4670	53	90	6	S	27
x 4635	53	45	2	S	24
x 4617	53	10	6	S	29
x 4647	53	15	6	R	25
x 4665	52	60	2	S	27
x 4620	52	15	6	R	28
x 4638	52	45	6	S	23
x 4604	52	30	2	R	24

TABLE XI (continued

Hybrid	Percent Damage(2)	Angle head to stem(3)	No. rows per head	Awn barbing	Height ins.
P. x H. 4686	52	90	2	S	29
x 4663	52	30	6	seg.	27
x 4646	51	15	6	S	27
x 4698	50	20	6	S	29
x 4639	50	75	6	S	20
x 46151	49	10	2	S	27
x 4643	49	30	6	R	26
x 4692	49	30	2	S	26
x 4680	49	90	6	S	27
x 4645	49	5	6	S	27
x 4650	49	80	6	S	27
x 4622	49	60	6	R	28
x 4654	48	90	2	S	26
x 4675	48	20	6	R	27
x 4685	48	20	6	S	27
x 4630	48	20	6	S	23
x 4659	47	15	2	S	26
x 4634	47	30	2	R	24
x 4615	47	10	2	S	28
x 4693	47	20	6	R	27
x 4653	47	90	2	R	28
x 4612	46	60	6	S	28
x 4610	46	20	2	S	27
x 4609	46	60	2	S	29
x 4624	46	20	2	S	28
x 4688	45	75	6	S	27
x 4657	44	30	2	S	26
x 4667	44	10	2	seg.	25
x 4608	44	15	6	R	28
x 4662	42	15	6	S	27
Prospect	41	5	6	S	26
P. x H. 4664	40	25	6	S	27
x 4614	40	10	6	S	28
x 4656	39	15	6	R	27

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(1) Determined at Swift Current - average of three replicates.
(2) Percent heads dropped - average of 4 tests grown in 1947.
(3) Note taken at maturity in degree; 0° = erect, 90° = right angles to stem.

DISCUSSION

The results obtained under the conditions prevalent during the time when these experiments were conducted clearly indicate that highly significant differences in susceptibility to grasshopper damage exist among barley varieties. As might be expected, the expression of these differences is dependent upon both the time and severity of the grasshopper infestation. The most striking differences in varietal susceptibility occur when a moderate infestation takes place just before the earliest maturing varieties begin to head. Under such conditions a range of damage from one to one hundred percent was obtained, (Cabri 1945). On one occasion, Piapot in 1944, a heavy infestation of grasshoppers, occurring when the varieties were in the seedling stage, resulted in complete destruction of the test with no apparent varietal differences. Severe infestations occurring when the earliest maturing varieties have headed, have resulted in a range of damage from twenty to one hundred percent with the majority of the varieties damaged, (Herschel and Burdett, 1947).

Such varietal differences in susceptibility are of little economic importance unless they prove to be consistent under conditions prevailing both at different locations over a fairly wide area and at the same locations at different years. The varietal reaction to grasshopper damage in ten tests, conducted over a period of four years, has been remarkably consistent, with one exception which will be discussed later. Correlation coefficients have been used as a measure of varietal consistency between tests since it was impossible to make a combined analysis of the data due to lack of homogeneity of the individual standard errors, unequal number of replicates or unequal number of varieties tested.

Grasshopper damage to barley varieties can be divided roughly into four types:

(1) leaf chewing - this is usually the first type of damage noticeable in a field provided that the crop is not mature when the infestation takes place.

(2) head dropping - as the crop nears maturity this is the predominant type of damage. Grasshoppers feed on the neck of the culm with the result that the head is left hanging or is completely severed. Such damage results in the greatest loss since the grain cannot be recovered.

(3) kernel chewing - instead of feeding as in (2), the grasshoppers feed on the glumes and kernels, usually from the apex of the seed towards the

base. The head is left standing but contains half-eaten kernels. Such damage usually occurs at the same time as head dropping.

(4) stem chewing - this type of damage occurs after the head has been dropped, and in severe cases the straw is eaten down to the ground level.

The percentage of heads dropped has been used as the criterion of damage in this study for several reasons. Such damage can be easily and accurately determined, it is highly correlated with leaf chewing and it is of the most economic importance. While leaf damage has often been considered of little importance, White (29) has recently shown that wheat plants defoliated when they are heading out or blooming suffer a loss of from 20 - 30 percent in yield. Stem chewing is of little economic importance since it usually occurs after the grain is a total loss. The limited observations on kernel chewing show some indication that such damage may be a varietal characteristic. Jacobson and Farstad (17) have reported kernel chewing as characteristic of Caesium wheat, whereas, in their tests, such feeding on other varieties of wheat was absent or negligible in comparison. On the basis of the limited data now available concerning this type of damage on barley varieties, it would appear that there is a high correlation between

head dropping and kernel chewing. However this is not true in every instance and the problem should be investigated further.

In attempting to link varietal damage with some agronomic character exhibited by the barley varieties in these tests, the most obvious relationship to study has been maturity and damage. The late maturing varieties grown in 1944, 1945 and 1946 always suffered the most damage. Such an observation might lead to the supposition that earlier maturing varieties escape damage because of unpalatability due to some character such as lack of moisture. However, the fact that grasshoppers will select out susceptible varieties even when none of the varieties have headed would indicate that some character other than actual maturity was involved. In order to examine this possibility further, the Prospect x Hannchen hybrids tested in 1947 included as many combinations of parental characters as possible. As might be expected, a significant positive correlation between damage and maturity was obtained, (ignoring for the moment data obtained at Herschel). A close examination of the data, however, shows some early maturing hybrids, for example, 4678, that suffered considerable damage; and some late maturing hybrids, for example, 4674, that suffered relatively

little damage. These examples, it is believed, give further indication that some factor other than maturity is responsible for the degree of grasshopper damage suffered by varieties of barley. A just criticism of the above discussion lies in the fact that the relative maturity of the hybrids was determined at Swift Current, while the damage was recorded in tests grown from 100 to 200 miles from Swift Current. However, an examination of the plots at the time the damage was estimated gave no reason to suspect that the relative maturity of the varieties and hybrids as recorded at Swift Current was in any way different at the test locations.

The results obtained at Herschel in 1947 were most surprising in view of the experience in other tests. There was a significant negative correlation between damage and maturity, even when the varieties and hybrids were studied separately. Lansdale, a very early maturing variety which was consistently resistant to grasshopper attack, even when exposed to severe infestations, lost ninety percent of its heads. On the other hand, Sanalta, a variety which matures at least two weeks later than Lansdale, and ordinarily is severely damaged, lost only fifty-six percent of its heads. Hybrid 4635, a medium late maturing line, proved to be the

most resistant under Herschel conditions, even though it was still green when the estimates of damage were made.

In the light of present knowledge, no explanation of this phenomenon is offered. Since the grasshopper population at Herschel was composed almost entirely of *Camnula pellucida* (Scudd.), it might be argued that such feeding was characteristic of this species. If such were the case however, it would be logical to expect some indication of similar feeding in plots at Gravelbourg and Shaunavon, where *Camnula pellucida* (Scudd.) was also present in considerable numbers. A more likely explanation lies in the fact that Herschel is 100 miles north of any of the other tests and consequently, since the soil type and environment are correspondingly different, the reaction of the barley varieties to grasshopper attack may vary accordingly. Further tests will have to be conducted, however, before arriving at any definite conclusions.

It is quite possible that significant correlation coefficients could be established between damage and several of the agronomic characters listed in Table 10. Such correlations, it is believed, would be spurious since the varieties under test do not represent a con-

tinuous range of characters from one extreme to the other. For example, a significant correlation coefficient probably could be obtained between damage and the number of rows per head. Such a correlation would be misleading however since no early maturing, 2-rowed varieties were included in the tests. The agronomic characters of the Prospect x Hannchen hybrids, listed in Table 11, are not subject to the same criticism, however, and it is obvious that such agronomic characters as height, angle of the head to the stem, number of rows per head and awn-barbing, are not correlated with susceptibility to grasshopper damage.

In view of the results obtained in this study, it may be concluded that the susceptibility of barley varieties to grasshopper damage is closely associated with maturity of the plants, but that the reaction of all hybrids and varieties cannot be explained on this basis alone. The striking differences in damage recorded in Table 7, and the consistency of the injury to individual hybrids and varieties in the various replicates, suggest a genetic basis for the differential injury noted. Such conclusions are in general agreement with the results of other investigators who have studied differential feeding of grasshoppers in other crops, (7, 12, 15, 17).

The fact that grasshoppers need specific hosts for maximum longevity and fecundity has been demonstrated by several investigators, especially by the researches of Criddle (9), Isley (16), Sanderson (24), Hodge (13), Tauber (27), and Brett (6). A common characteristic of these studies lies in the fact that different crops were tested as food for grasshoppers. As far as is known, no literature is available on the effect of feeding different varieties or selections within a species. In view of the striking effect on the longevity and fecundity of grasshoppers when fed different crops, and the fact that grasshoppers show a marked preference for certain varieties within a species, it would not be unreasonable to expect similar, but perhaps less striking, differences in these characters if the grasshoppers were fed on varieties for which they have a natural aversion.

Since the grasshoppers in the present study had a free choice of many varieties and hybrids, it must be kept in mind that the results probably indicate preference rather than resistance. The full importance of the wide differences in varietal injury recorded in these tests is dependant upon further investigations.

SUMMARY

1. A study was undertaken in 1944 to determine whether there are consistent differences in the amount of damage suffered by barley varieties exposed to grasshopper attack; and if so, to determine which, if any, agronomic characters may be associated with "resistance".

2. A number of varieties and hybrids of barley were grown in replicated tests exposed to natural infestations of grasshoppers during the period 1944 - 1947 inclusive.

3. There were consistent varietal differences in the amount of grasshopper injury sustained in 10 of the 11 tests. No explanation for the exceptional results obtained at Herschel in 1947 is offered.

4. As a general rule, late maturing varieties and hybrids suffered the most damage. Evidence is submitted to show that some factor other than maturity alone must be responsible for differences in varietal susceptibility.

5. There did not appear to be any correlation between damage and such agronomic characters as height, leafiness, angle of head to stem, number of rows per head, awn barbing, or susceptibility to shattering.

6. The results obtained in this study indicate preference rather than "resistance". The full significance of the differential injury recorded will be dependent upon further investigations.

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